

# Oyster Restoration Project

## Shimmo Creek, Nantucket, MA



Submitted by: Leah Cabral  
Assistant Biologist  
Town Of Nantucket  
Natural Resources Department  
2 Bathing Beach Rd.  
Nantucket, MA 02554  
508-228-7230  
lcabral@nantucket-ma.gov



## Oyster Restoration in Shimmo Creek, Nantucket, MA

### Background

The Eastern/American oyster (*Crassostrea virginica*) is found in estuaries, bays, tidal creeks, drowned river mouths, and behind barrier beaches along the east coast of North America from Canada to the Gulf of Mexico and from Mexico to Venezuela (Sellers and Stanly et al. 1984). Oysters in Massachusetts are found in brackish ponds and bays and are limited to sub-tidal environments due to ice scouring, growth rates are limited by temperature, recruitment is periodic and predators tend to have a large impact on survival (Kennedy et al. 1996).

World-wide oyster habitat and populations have declined by an estimated 85% worldwide in the last 100 years (Beck et al. 2011; Figure 1.). In the United States, there has been an estimated 88% decline in oyster biomass, with oyster populations being strongly affected in estuaries along the Atlantic coast. “The most dramatic losses of Eastern oyster habitat were recorded from the northeast Atlantic coast, with less than 6 percent of historic extent remaining...” (Zu Ermgassen et al. 2012). Significant population declines are due to a number of reasons including: over-harvesting, not returning suitable substrate (oyster shell) back to the water, habitat loss, sedimentation, disease and poor water quality (Wilberg et al. 2011). In response to worldwide population loss of a keystone species, scientists have made significant efforts to restore oyster reefs and beds. Oyster restoration projects are prevalent all over the coastal United States. In Massachusetts, reefs have been established on Martha’s Vineyard, and in Wellfleet and Fairhaven with more pending projects elsewhere in the state.

According to the Nantucket Shellfish Management Plan (SMP) adopted in October 2012, the Town has purchased small oyster seed (19-30mm) for grow-out purposes in recent years. The seed was released in Nantucket Harbor to enhance natural broodstock populations and improve water quality. Additionally, bags filled with shell and oyster larvae were remotely set in Madaket Harbor. In the last two years, the Natural Resources Department (NRD) has expanded its shellfish production to include oysters during the shoulder season (SMP High Priority: Goal 1, Objective 1, Recommendation 2). In the summers of 2014 and 2015, the Brant Point Shellfish Hatchery conducted a proof of concept study that included spawning oysters, rearing larvae, and remotely setting 3 million spat on recycled oyster shell. This study measured growth and settling rates as well as provided broodstock to use for future spawns or seed the oyster reef.

In 2014, with the help from the Nantucket Shellfish Association, the Town of Nantucket established a successful Shell Recycling Program: “Shuck It for Nantucket”. Instituting a shell recycling program was a high priority in the SMP (Goal 1, Objective 3, Recommendation 2). Oyster shells are now a limited resource because for years they were disposed of in landfills instead of being returned to the marine environment. “Shell recycling programs are also becoming widespread (e.g. North Carolina, Florida, New Hampshire) in an effort to maximize

the retention of shell for restoration projects in coastal areas” (Brumbaugh et al. 2009). During an oyster’s life cycle, larvae need to attach to a suitable substrate (ideally oyster shell, but other kinds of hard substrates will work) in order to mature into an adult (Figure 2.). “Oyster shell is a biogenic substrate that allows oysters to build reefs by providing a hard substrate for the attachment of oyster larvae generation after generation” (Brumbaugh et al. 2009). Shuck It for Nantucket has collected more than 65,000 pounds of oyster and quahog shells from 30 local restaurants and raw bars. Currently, the shell is curing on land at the Department of Public Works under the Division of Marine Fisheries (DMF) Shellfish Planting Guidelines to prevent disease and pathogen transfer to the Harbor (Hickey et al. 2015). The reclaimed shell will serve as a pH buffering source and be used to establish Nantucket’s first oyster restoration project (SMP: Goal 1, Objective 1, Recommendation 3).

### **Purpose**

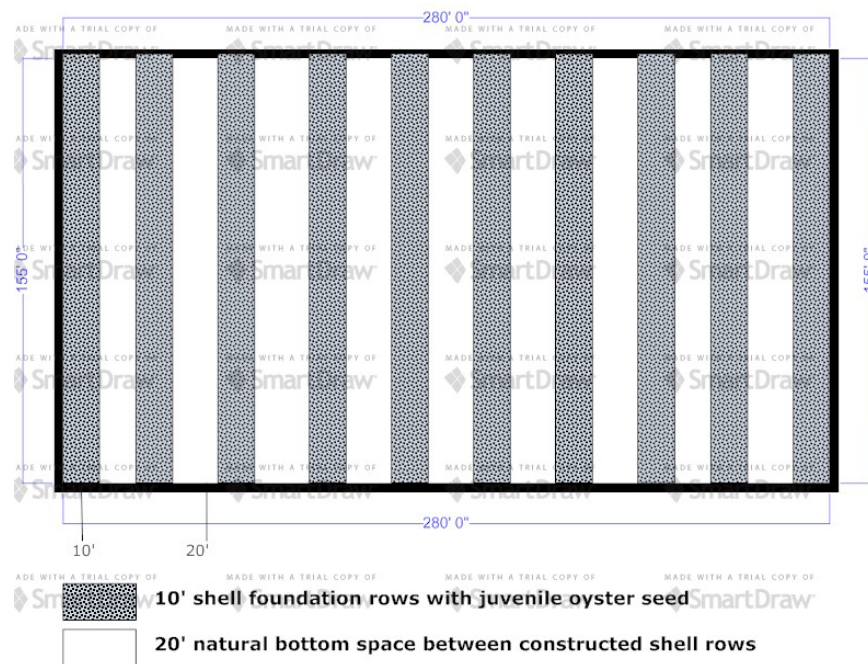
The long-term purpose for the restoration project is to establish the population of a native shellfish species, *Crassostrea virginica*, in Nantucket waters in order to establish a healthy coastal ecosystem supporting an array of species. Nantucket’s wild oyster populations formally plentiful but presently functionally extinct (anecdotal evidence) have followed the same trend as populations elsewhere in the region. Population declines are due to habitat degradation including poor water quality, overharvesting, and loss of suitable substrate. Small, wild populations can be found attached to rocks or bulkheads in Easy Street Basin and Sesachacha Pond. This project fulfills fourteen recommendations in the SMP; six are high priority (Table 1.).

### **Project Scope**

The scope of this project includes the placement of approximately 100 cubic yards of reclaimed, loose cultch in the form of cured oyster and quahog shell to achieve a reef relief height between 4-6”. “Oyster shells have also been placed in coastal waters for use in oyster culture (serving as cultch, a settling surface for oyster seed) and to create or improve habitat for native oysters and other organisms” (Cohen et al. 2009). Schulte et al. (2009) found that reef height was a major influence for oyster reef success because it drove oyster abundance and density. High relief reefs maximize oyster growth and survival and minimize disease and sedimentation due to optimal flow rates. The reef will be sub-tidal to avoid damage caused by ice scouring and will consist of a one acre area in Shimmo Creek, a sub-embayment of Nantucket Harbor (Figure 3.).

Ideally, the cultch will be placed in ten parallel strips with 10 cubic yards per strip. The actual configuration of cultch will depend on machinery available, the number of volunteers available, the site’s water depth, how much the cultch disperses in the water column, and pile height will depend on how hard the underlying substrate is. The Town of Nantucket Natural Resources Department will collaborate with a number of restoration experts including Dr. Anamarija Frankic (UMASS Boston), Jon Kachmar and Matthew Pelikan (The Nature Conservancy) and Dr. Jon Grabowski (Northeastern University). The project will follow The

Nature Conservancy’s design: “The objective is to achieve a somewhat patchy distribution of cultch, with 50-75% of the bottom covered with shell and the remainder left available for burrowing invertebrates or aquatic vegetation to grow, enhancing the overall diversity of the site” (Pelikan et al. 2015). Additionally, “Broad scale placement of shell or shell fragments at high density on the bottom has been shown to increase recruitment of hard clams [Kraeuter et al. 2003] and this kind of patchy habitat also serves to increase biodiversity” (Hewitt et al. 2005).



In addition to cultch placement, remote set oyster seed and/or eyed larvae will be produced by the Brant Point Shellfish Hatchery to supplement the fishery and aid in ecological restoration (SMP High Priority: Goal 1, Objective 1, Recommendation 1). Broodstock will be added to the reef to increase spawning events and natural recruitment. “Stocking adult shellfish in relatively high densities is likely to improve the chances of successful spawning and reproductive success. This strategy may be useful for ‘jump starting’ populations from a range of bivalve species including oysters” (Brumbaugh et al. 2006).

The Town of Nantucket anticipates the reef to be closed to any shellfishing and act as a “sanctuary”. Continuing to develop spawning sanctuaries through the use of spawning cages is a high priority in the SMP (Goal 1, Objective 3, Recommendation 1) and will provide other areas in the harbor with oyster larvae which may help re-establish populations. “Few bivalve fisheries, if any, have been managed with any evidence of long-term sustainability, both in the U.S. and in many other parts of the world. Oysters in particular have posed a unique challenge to fishery managers since fishing activities for these species, unlike most fish and other mobile organisms, tends to simultaneously remove their habitat” (Brumbaugh et al. 2006). Under the Town of Nantucket’s Shellfishing Policy and Regulations Section 2.8 Habitat Sensitive Areas: “No commercial or recreational shellfishing may occur in areas deemed ‘habitat sensitive’ and have a

posted closure by the Board of Selectmen or its designee” (adopted March 2015). This regulation will allow the Town to close the reef for three years. Currently, DMF allows shellfish closures in approved areas for a period no longer than three years without petitioning for an extension. The petition has to be filed with the DMF by the Town of Nantucket stating the proposed regulations that would enact the closure (Hickey et al. 2015). The Natural Resources Department is already in contact with the DMF in case the Town decides to keep the reef as a spawning sanctuary longer than three years. The idea of closing planted shellfish areas for more than three years is fairly new in Massachusetts and the town of Falmouth is the first to do so in the state. Not only will this project restore oysters, but it will provide habitat for many different species including fish, shellfish (scallops, hard and soft shell clams), crustaceans (crabs, shrimp), and water fowl.

### **Project Goals**

1. Restore populations of the native oyster species, *Crassostrea virginica*, in Nantucket waters in order to establish a healthy coastal ecosystem providing habitats to support an array of species.
2. Stock approximately 250,000-1,000,000 oyster spat on shell and a determined amount of broodstock for several years in order to supplement natural recruitment until the reef persists as self-sustaining with multi-year age classes.
3. Establish an educational platform for local and visiting scientists, students, and the community to study the ecological benefits of a small-scale oyster reef. Topics may include but are not limited to water quality, species biodiversity, and shoreline stabilization in one of Nantucket Harbor’s sub-embayment.
4. Long-term monitoring of the oyster reef including oyster size-frequency distribution, oyster densities, reef height, and sex ratio will provide information about growth, recruitment, survival of cohorts, and reef success.
5. Gain public support and volunteer interest about the importance of shell recycling and oyster restoration.

### **Benefits**

Oyster reef habitat provides many ecological and economic benefits. The table below explains ecosystem services and bioeconomical methods provided by oyster reefs. The bioeconomic model explains human uses of ecosystems in terms of production and consumption in dollar values (Kragt et al. 2012). All of the ecosystem services and process that oyster reefs provide, listed below, are the driving force for this restoration project. Not all bioeconomic examples are pertinent to Nantucket but may be applicable to restoration projects elsewhere.

<i>Table 2. Ecosystem services provided by oyster reef habitat.</i>			
<b>Ecosystem service</b>	<b>Ecosystem process</b>	<b>References</b>	<b>Bioeconomic model valuation method</b>
Water quality improvement	Chlorophyll a removal	Newell et al. 2002, Grizzle et al. 2006	Replacement cost of using sewage treatment plant to remove nitrogen, nitrogen credit market
	Reduce turbidity	Newell and Koch 2004	
	Denitrification	Piehlner and Smyth 2011	
	Increase benthic algal or pseudofecal production	Newell et al. 2002	Not applicable
	Bacterial biomass removal	Cressman et al. 2003	Not applicable
Seashore stabilization	Shoreline stabilization	Meyer et al. 1997	Cost of a sill to stabilize salt marsh and seagrass habitat, value of protected habitats
Carbon burial	Bury carbon dioxide	Not applicable	Traded carbon pollution credits
Habitat provisioning for mobile fish and invertebrates	Increased fish production	Peterson et al. 2003	Commercial dockside landings value, recreational fisher willingness to pay for improved fishing
Habitat for epibenthic fauna	Increased epibenthic faunal production and biodiversity	Wells 1961, Bahr and Lanier 1981, Lenihan et al. 2001	Already captured in fish values
Diversification of the landscape	Synergies among habitats	Micheli and Peterson 1999, Grabowski et al. 2005	Not applicable
Oyster production	Increased oyster production	Heral et al. 1990, Rothschild et al. 1994, Lenihan and Peterson 1998, 2004, Grabowski and Peterson 2007	Commercial oyster dockside value, recreational value-license program

Table 2. Ecosystem and bioeconomic services provided by oyster reef habitat (Grabowski et al. 2012).

Oysters filter between 1-10 liter/hour/gram dry weight or between 30 and 50 gallons of water a day helping to improve water quality (Newell et al. 1996). Oysters are suspension feeders and remove floating particulate matter (phytoplankton containing chlorophyll a, bacteria, nutrients, and sediment) from the water column reducing turbidity. With lower turbidity, light can penetrate further down in the water column allowing eelgrass growth (Newell and Koch et al. 2004). This may be a cost effective strategy to restore eelgrass while removing stressors (excess nutrients) (SMP: Goal 1, Objective 2, Recommendation 3). Oysters in large densities can help prevent harmful algae blooms such as red tide (Peabody and Griffin et al 2008). Not only do oysters remove carbon from the water column to construct their calcium carbonate shells but they also decrease nitrogen levels in the marine environment.

Restoration scientists and government workers have come together and determined that using oysters to remove/reduce nitrogen from bays, estuaries, and ponds is an affordable option to supplement sewerage projects. High nitrogen loads lead to algal blooms that block light and when the algae dies it is decomposed by bacteria in the sediment that can cause oxygen depletion. These results of high nitrogen are detrimental to eelgrass, shellfish, crustaceans, and finfish. Three towns in Cape Cod: Falmouth, Mashpee, and Wellfleet have restored oysters in order to reduce their total maximum daily load of nitrogen. A natural resources specialist from the Cape Cod Commission, who is leading a waste water management planning process, stated “We’re very supportive of the work to identify the role of oysters and other shellfish in helping to manage nitrogen in our coastal embayments. We see that as a potentially great alternative

approach to managing nitrogen in the water body, as opposed to a traditional solution by putting pipes in the ground” (Massachusetts Municipal Association et al. 2014).

According to Kellogg et al. (2013), denitrification by oysters works as the following: “Phytoplankton use dissolved inorganic nitrogen for their growth (A), oysters and other reef-associated organisms filter phytoplankton and other particulate organic matter from the water column (B), some of the associated nitrogen is incorporated into organisms and some is deposited on the surface of the sediments (C), and, given the right conditions, a portion of the nitrogen in these biodeposits is transformed into nitrogen gas (D) which diffuses out of the sediments back to the atmosphere (E) where it is no longer available to phytoplankton for growth” (Figure 4. & 5.).

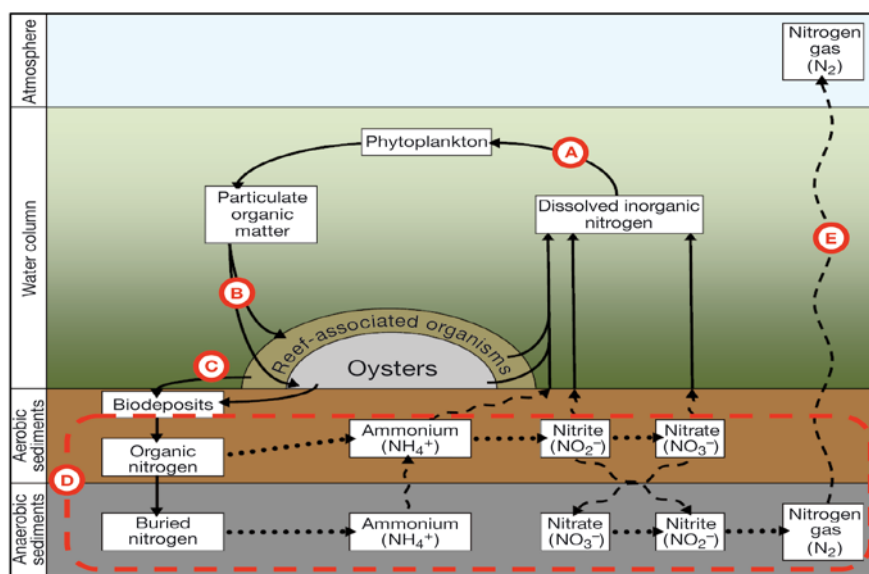


Figure 4. Nitrogen cycle on an oyster reef (Newell et al. 2005).

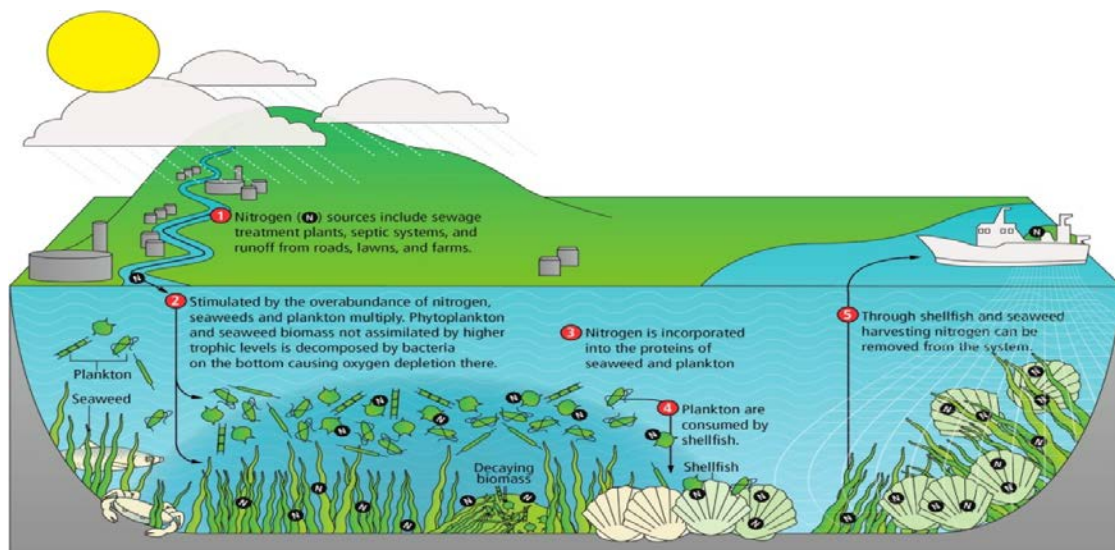


Figure 5. Nitrogen cycle in regards to shellfish and seaweed aquaculture (Rose et al. 2014).

Ocean acidification is a global concern and becoming more prevalent on a local level. As carbon dioxide levels increase in the atmosphere it increases in the oceans causing it to become acidic. “This affects marine ecosystems on a global scale in ways we are only beginning to understand: for example, impairing the ability of organisms to form shells or skeletons, altering food webs, and negatively affecting economies dependent on services ranging from coral reef tourism to shellfish harvests” (Kelly et al. 2011). One way to combat ocean acidification on a local level is returning shell back to the water. Oyster shells are made out of calcium carbonate, which is basic on the pH scale. Therefore, as shells naturally deteriorate, calcium carbonate is released back into the water column increasing the pH. “Returning crushed shell material to coastal habitats to approximate densities found in healthy clam populations can substantially increase pH and mitigate localized acidification impacts [Waldbusser et al. 2011, Green et al. 2009] ” (Kelly et al. 2011).

In addition to water quality benefits, oyster reefs act as buffers between waves and the shore, reducing shoreline erosion. “Oyster reefs are often found seaward of marshes and have been shown to mitigate erosive wave energies, stabilize sediments, and reduce marsh retreat” (Meyer et al. 1997). In areas where erosion is prevalent, loose shell cultch is not the best method for reef establishment because high wave energy causes sediment to bury the shell. An alternative to shell are marine-friendly, concrete structures called oyster domes (Figure 6.). The domes provide three-dimensional structures for wave attenuation, aid in sediment deposition, and provide habitat for both oysters and fish (Gedan et al. 2010). According to Gedan et al. 2010, “Living shoreline restorations of this type are appealing because they provide the service of hard coastal defense structures (e.g. breakwaters, seawalls) with the ancillary benefits of ecological restoration (Swann 2008) and, in addition, are self-maintaining. Perforated hard structures such as reef balls (i.e. oyster domes) promote sedimentation at the wetland seaward margin (Meyer et al. 1997; Piazza et al. 2005), allowing restoration and expansion of coastal wetlands in wave climates that might not otherwise permit traditional wetland restoration.” Oyster domes may be a good option for north facing shorelines in Nantucket Harbor that are experiencing erosion. This results in expensive coastal dune restoration projects in areas such as Pocomo and Quaise. If oyster domes were deployed in these two areas, oyster spat would colonize fairly easily because spat is present from aquaculture leases located in the Head of the Harbor. Oyster domes could decrease erosion while serving as a habitat for oysters and other fish and shellfish species.

In addition, oyster reefs diversify marine landscapes while providing habitat for an array of species including fish, invertebrates, epi-benthic fauna, and birds (Figure 7.). Several studies have indicated that three-dimensional oyster reefs attract greater numbers of resident and transient species when compared to sand or mud bottom habitats (Posey et al. 1999, Lenihan et al. 2001, Kingsley-Smith et al. 2013). A study by Mann and Harding et al. (1998), determined that oyster reefs serve as a “nursery” for small to intermediate fish and in turn this causes larger pelagic fish such as Striped Bass (*Morone saxatilis*), Black Sea Bass (*Centropristis striata*), Bluefish (*Pomatomus saltatrix*), and Flounder (*Paralichthys dentatus*, *Pseudopleuronectes*

*americanus*) to be found on or around oyster reefs. In Nantucket, a restored oyster reef may increase the abundance of these larger fish that are sought after by fishermen. Additionally, oyster reefs serve as critical foraging habitat for endangered or threatened bird species such as the American Oyster catcher (*Haematopus palliatus*), and Piping Plover (*Charadrius melodus*) (Kingsley-Smith et al. 2015; Natural Heritage et al. 2016).

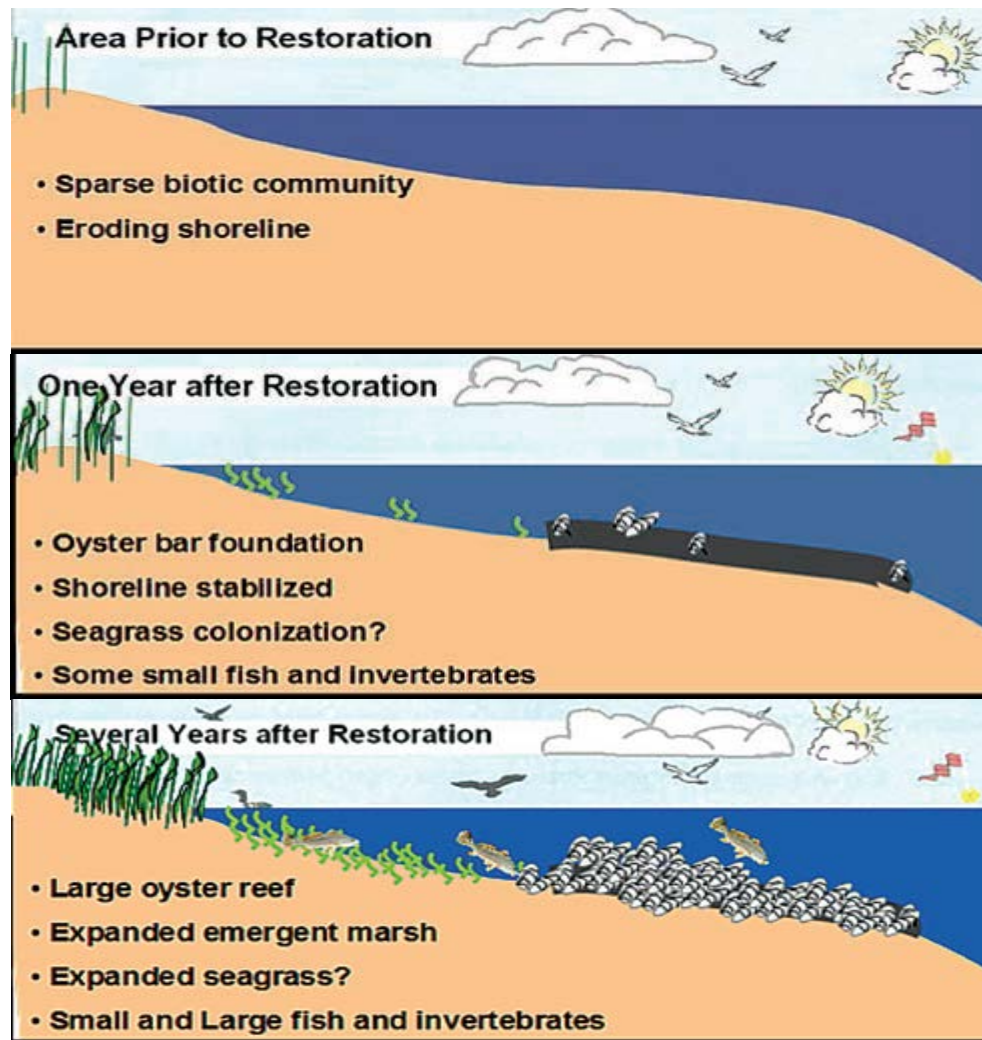


Figure 7. Possible effects of oyster restoration on habitats (Baggett et al. 2014).

### Site Selection

Shimmo sub-embayment is located between Pimney's Point and Abram's Point on the southern shore of Nantucket Harbor. It is tidally influenced with a high and low tide twice a day with a narrow, channel that opens up to the Harbor. Shimmo consists of two water bodies that are partially divided by land and connected by a single, shallow channel. It comprises a barrier beach, salt marsh, and two freshwater sources that are located at the head of the embayment (Figure 8 & 9.). The prospective reef will be located in the embayment closest to the harbor, which is 4.26 acres in extent but the reef will only comprise one acre. It has relatively shallow

water (1.5m at high tide) which will simplify cultch deployment, monitoring, and maintenance. Shimmo is easily accessible by both boat and foot and out of the way of most harbor users.

This area is ideal for oyster restoration for a number of reasons. Shimmo's bottom type consists of sand and anoxic soft sediment with no habitat value. According to the Division of Marine Fisheries guidelines, Shimmo would qualify as an acceptable site for aquaculture or shellfish restoration because it is in an approved area for shellfish propagation and void of eelgrass (*Zostera marina*) and other shellfish species. Additionally, MassGIS (Figure 10.) depicts this area as suitable for growing Eastern oysters. Oysters are capable of surviving a wide range of habitat conditions. The range and optimal conditions for oysters in the northeast are the following (Shumway et al. 1996):

**Depth:**

Range: 0-11 meters

Optimal: 0.6- 5 meters (MacKenzie et al. 1996)

**Salinity:**

Range: larvae (10-27.5 ppt), adults (5-40ppt)

Optimal: 12-28 ppt

**Temperature:**

Range: -2°C to 36°C (28.4°F to 96.8°F)

Optimal: larvae (14-28°C; 57.2°F - 82.4°F), adults (20-30 °C; 68°F - 82.4°F)

**Substrate:**

Optimal: larvae prefer clean oyster shell; adults can tolerate various substrates including mud

**pH:**

Optimal: larvae (6.75-8.75)

**Dissolved Oxygen (D.O.):**

Range: 3mg/L or above. Sub-tidal oysters can close their shells and use anaerobic respiration for several hours if the water has low D.O. (NOAA)

**Hydrographic circulation:**

Light enough to keep larvae near existing reefs but with enough exchange to maintain a good food supply and near neutral silt balance on the oyster reefs (Lenihan et al. 1999).

Shimmo's range for oysters:

**Depth:** Low tide: 0.8m High tide: 1.5m

**Salinity:** 31.6ppt

**Temperature:** 23.1°C (73.5 °F)

**Substrate:** Reclaimed, cured oyster and quahog shells

**pH:** To be determined

**Dissolved Oxygen (Winkler):** 4.10 mg/L

**Bottom Type:** Sand and anaerobic soft sediment

**Hydrographic circulation:** To be determined

According to the optimal conditions described above by Shumway et al. (1996), Shimmo's depth, temperature, and substrate are in optimal range for oysters. The salinity level

and dissolved oxygen is in range but not optimal. These two parameters will be monitored closely in the upcoming water quality sampling season to ensure that oysters can thrive in this area. If oysters are deemed unfit for Shimmo then another restoration site will be considered.

### **Pre-Restoration Monitoring**

The Town of Nantucket's oyster restoration project's monitoring protocol will follow the "Oyster Habitat Restoration Monitoring and Assessment Handbook," which is the result of a working group made up of restoration scientists and practitioners from around the coastal United States. The work group found that many oyster reef restoration projects in the past have not been monitored to the extent that allows for comparison. As a result, the group's goal was to "...develop recommendations for a set of Universal Metrics that should be monitored for all oyster restoration projects. The working group also developed guidelines for assessing optional Restoration Goal-based Metrics" (Baggett et al. 2014). These specific monitoring techniques and performance criteria allows for post-restoration comparisons between restoration projects in different regions.

In order to determine the ecological impacts that an oyster reef provides, a control site needs to be monitored as well. "Control sites are unaltered areas that mimic the pre-restoration conditions (e.g., sand or mud substrate). Control sites should have physical characteristics (e.g., flow, wave action, tidal range, salinity, proximity to open water, water temperature, freshwater influence, substrate type, water depth, etc.) similar to the restored sites. Control areas would allow for determination of the degree of local enhancement resulting from the project and reference areas could be used to determine if the restored reef is performing to the level of a healthy natural reef" (Baggett et al. 2014). This summer the Natural Resources Department will determine an appropriate control site.

A number of pre-restoration surveys started in the summer of 2015 and will continue through 2016 until the reef is established in 2017. When the reef is established these surveys will continue as post- construction monitoring. The Natural Resources Department will perform the monitoring surveys unless outside help from monitoring scientists is needed. As stated previously, habitat evaluations done by NRD employees and reviewed by the Division of Marine Fisheries deemed that there is limited habitat value in Shimmo Creek due to the presence of anoxic sediment.

Pre-restoration water quality sampling started in August 2015 and only included two sampling dates (see Figure 11; Table 3.). Pre-monitoring will continue throughout the 2016 sampling season (May-September) and continue yearly after reef establishment. Parameters measured are: salinity, dissolved oxygen, temperature, conductivity, phosphate, ammonium, nitrate, nitrite, total dissolved nitrate, particulate organic nitrogen, particulate organic carbon, chlorophyll a, and Phaeophytin. Calculated from the measured parameters data for total pigments, total nitrogen, dissolved inorganic nitrogen, and dissolved organic nitrogen can be obtained. This summer, pre- reef dissolved oxygen levels will be monitored in real time using a

HOBO data logger. It will take readings every 15 minutes throughout the summer to obtain an accurate D.O. reading both on the control site and the future restoration site. The HOBO will also take data on temperature and light penetration. Ideally, light penetration should be greater following reef construction because oysters filter particulate matter out of the water column. The logger will be located 4-6" off the bottom to ensure it is not in anoxic mud. When the reef is built, the HOBO will be replaced with a SONDE to measure dissolved oxygen, conductivity, salinity, temperature, pH, and chlorophyll in real time. This data provides a way to evaluate objective 2 to determine how a small-scale oyster reef in a sub-embayment can affect water quality. In addition water quality monitoring fulfills two medium priority recommendations in the habitat management section of the SMP (Goal 1, Objective 1&3, Recommendation 5&3).

Spat settlement will be monitored using oyster spat collectors, which will be deployed in late June or early July 2016 (SMP High Priority: Habitat Management Goal 1, Objective 3, Recommendation 5; Shellfish Resources Goal 1, Objective 3, Recommendation 2). The Nature Conservancy and Buzzards Bay Coalition customized steel mesh lobster traps that hold 4 ceramic tiles in order to monitor natural spat settlement (da Silva Quintal et al. 2014; Figure 12 & 13). Three spat collectors will be deployed in Shimmo Creek and will be monitored monthly. They will be retrieved for analysis in October 2016.

In October 2015, a predator pilot project was deployed in Shimmo Creek (Appendix II). A "mini reef" (1.13m x 0.82m) was built using plastic clam trays filled with 210,000 oyster spat on shell. The project's objectives are to identify and quantify oyster predators in Shimmo Creek, measure the impacts on shellfish resources (oysters) during various life stages from predators, implement a predator management protocol if necessary, specifically look at the impacts by an oyster predator called the mud blister worm (*Polydora*), and determine if 4" or 6" reef relief height is appropriate for Shimmo. The objectives will be monitored by dive surveys and time lapse cameras. If the oyster seed did not survive the winter then it will be replaced with either oyster singles or spat on shell ordered from Muscongus Bay Aquaculture Inc. This pilot project fulfills three SMP objectives (Habitat Management Goal 1, Objective 3, Recommendation 5; Shellfish Resources Goal 1&2, Objective 1, Recommendation 2&1).

In order to determine pre-restoration sediment type and assess infaunal invertebrates either a 15 cm corer or Ekman sampler will be used. The sample will be washed over a 2 mm and a smaller 500 um mesh screen to catch specimens. With the help from Andrew McKenna-Foster, director of Natural Science at the Maria Mitchell Association, invertebrates will be identified, enumerated, and dry weight (g) will be determined. Annual core or Ekman samples will continue to be taken after the reef is build to determine if sediment composition and infaunal species change due to reef establishment.

To survey transient crustaceans and fish, seine net surveys and multiple minnow traps will be deployed at random locations in Shimmo Creek once a month to quantify the density (catch per unit effort; individuals/hour), wet weight (g/m<sup>2</sup>) and length (mm) for every species.

Maria Mitchell interns will help with monthly seining and species identification. In addition, two time lapse cameras will be deployed on the “mini reef” to monitor the presence of larger fish species that may use the reef as foraging habitat. These baseline surveys will continue post construction in the summer months to observe if the oyster reef does attract multiple species.

Shoreline loss/gain, profile/elevation, as well as density of marsh plants will be monitored throughout the reef project. Before construction, a permanent transect line will be established with three transect lines set perpendicular to the reef with specific bearings to monitor shoreline loss/gain and profile/elevation. The lines will be measured using a tape measure or advanced surveying instruments in order to produce a topographic survey which will be entered into ArcGIS. Shoreline loss/gain and profile/elevation will be measured once before construction, within three months post-construction and annually thereafter. Plant density will be determined annually by placing m<sup>2</sup> transects every 2 m along the permanent transect lines. The lines should extend at least 4 m into the marsh. Live shoots per m<sup>2</sup> and percent coverage of each plant species will be recorded.

Submerged aquatic vegetation (SAV) will be monitored annually during the fall survey at both the restoration and control sites. Measurements will be taken at three locations, 1m shoreward of the reef, half way between reef and shoreline, and 1m seaward of the shore along transect lines. At each sampling spot a quadrat (m<sup>2</sup>) will be used to count the number of eelgrass shoots within it as well as a visual estimate of percent substrate covered by both eelgrass and macro algae within the quadrat. The modified Braun-Blanquet scale will be used for percent coverage (Fourqurean et al. 2001):

- 0 = no seagrass present in quadrat
- 0.1 = a solitary shoot, <5% cover
- 0.5 = less than 5 shoots, <5% cover
- 1 = greater than 5 shoots, <5% cover
- 2 = greater than 5 shoots, 5 – 25% coverage
- 3 = greater than 5 shoots, 25 – 50% coverage
- 4 = greater than 5 shoots, 50 – 75% coverage
- 5 = greater than 5 shoots, 75 – 100% coverage

SAV density (shoots/m<sup>2</sup>) and percent coverage measurements will provide data on secondary effects of oyster reefs. Baggett et al. 2014, states “The presence of oyster habitat may increase SAV coverage through water clarity improvements and/or sediment stabilization.”

### **Post-Restoration Monitoring**

Post reef monitoring surveys will be performed annually in September or October allowing spat to grow to a sufficient size (>10 mm). Sample size will be determined at a later date using the equation  $n = z\alpha 2\sigma^2/d^2$ . There are four universal metrics that should be sampled for every reef regardless of restoration goals; they include: oyster density, oyster size-frequency

distribution, reef areal dimensions, and reef height (Baggett et al. 2014). The universal metrics allow for assessment between restoration projects within and across regions.

Live oyster density (individuals/m<sup>2</sup>) is the number of live oysters including recruits. This metric will be analyzed using m<sup>2</sup> quadrats at random sampling sites. Either all oysters will be removed within the quadrat and counted or divers will count densities underwater. If available, spat will be remotely set on scallop shell to help distinguish between natural set and hatchery seeded oysters.

Oyster size frequency distribution measures oysters along different size classes and provides information about oyster growth and survivorship/mortality of cohorts (SMP Goal 3, Objective 1, Recommendation 2). This can be obtained by using the same oysters collected for oyster density metrics. At least 250 oysters per reef should be measured (length in mm) using calipers and placed into assigned 5 mm classes (0-5mm, 6mm-10mm, etc).

Reef areal dimension (m<sup>2</sup>) consists of the project's footprint and the reef area. The footprint is the actual extent of the reef project and can be acquired by marking continuous GPS points while walking or kayaking around the project's perimeter. In order to determine reef area transects are run in a grid pattern through the project footprint using either side-scan or multi-beam sonar while taking continuous GPS points. Side-scan sonar efficiently creates images of large areas of the seafloor. Multi-beam sonar emits sound waves to acquire water depths. This equipment can be expensive so we may have to borrow it or hire a professional to perform reef area analysis.

Reef height (m or cm) measures the mean height in relation to the adjacent substrate; in addition, minimum and maximum reef height will be measured. The relief height of the oyster reef may be too low for multi-beam sonar or side-scan sonar to use. If so, reef height will be measured using a ruler or graduated rod every meter along the long axis of the reef. The ruler will be placed vertically on top of the sediment and another ruler will be placed horizontally on top of the shell to obtain an accurate reading. The average of all height measurements will determine mean reef height. If the reef consists of smaller patch reefs then reef height measurements will be taken along each of the patches and a mean overall reef height will be calculated. Reef height will be measured 3 months post construction and every year after.

Percent cover of reef substrate (oysters and cultch) estimates available habitat for oyster spat to settle on. This can be determined before the shell is removed from the reef using the same quadrats for oyster density and size frequency. The quadrat will contain a grid pattern and the number of squares containing shell will be counted. Grids containing shell will be divided by total number of grids to determine percent coverage. Measurements will be taken three months post construction and every year after.

The ratio of males to females, also known as sex ratio, will be determined annually using the same oysters that determined oyster density and size frequency distribution. Oysters are

protandrous hermaphrodites meaning that they change sex from male to female as they grow older (Baggett et al. 2014). “This ratio can provide valuable information concerning generation times and the susceptibility of the population to collapse” (Mann and Powell et al. 2007). Sex ratio is a good indicator of the reef’s egg production. At least 25 random oysters (> 25 mm) will be sampled across available size ranges. A pipette will be gently inserted into the gonad to obtain a sample and placed on a glass microscope slide. The sex will be determined by placing the slide under the microscope and seeing either eggs or sperm. To calculate sex ratio, the number of males will be divided by the number of females.

### **Maintenance**

Oyster reef maintenance is anticipated to be minimal. Remote set oysters produced by the Brant Point Hatchery will be placed on the reef for the first couple of years until it becomes self-sustaining with natural oyster spat. If the bottom sediment is too soft, cultch can get buried causing the reef height to decrease. The rate of shell accretion must be greater than shell loss for an oyster reef to persist (Baggett et al. 2014). “Shell accretion occurs through recruitment, growth, and natural mortality (e.g. Mann and Powell 2007) whereas shell loss can be caused by taphonomic sources such as bioerosion, dissolution, and disarticulation (e.g., Powell et al. 2006) as well as habitat destruction and burial of shell (e.g. Mann and Powell 2007)” (Baggett et al. 2014). Therefore, if the reef’s rate of shell loss is greater than accretion then more cultch may need to be added to account for the loss.

### **Timeline**

July 17, 2015: Nature Conservancy visit to help with site selection  
July 24, 2015: Oyster cages deployed for oyster growth study  
August 13, 2015: Site selection dive surveys at Shimmo  
October 7, 2015: Predator study deployed  
March 2016: Restoration draft proposal completed and reviews sent out  
April 2016: Project design finished  
April 2016-April 2017: Obtain necessary permits  
June-September 2016: Pre-reef monitoring surveys  
May 2017: Spat on shell production  
July 2017: Cultch placement  
August 2017: Spat and broodstock placement  
September 2017: Post-reef monitoring surveys  
November-December 2017: Work up monitoring results and develop final report  
July 2018: Spat on shell placement  
September 2018-2023: Post- reef monitoring surveys

### **Conclusion**

It is our hope and ultimate goal that this restoration effort will demonstrate the ability for Nantucket’s ecosystem to accept and prosper under directed and intentional restoration efforts.

This project will be used as a foundation for decisions used in future restoration efforts and help to dictate the scale of effort that will be needed to see a substantial impact of return in the form of ecosystem services. For example, the reef will provide habitat to species ranging from eelgrass to Striped Bass, aid in improving water quality, combating ocean acidification on a local level, and prevent erosion. Additionally, it will serve as an educational platform for the local community and visiting scientists to study, collaborate with others, and share data. A webpage specific to the oyster restoration project will be available on the Town of Nantucket's website. Real time data incorporating all of the monitoring aspects will be made available for the public to use. The reef will be closed for three years and a petition may be filed through the DMF to keep it closed to shellfishing for a longer period of time.

## Reviewers

Jeff Carlson  
Town of Nantucket  
Natural Resources Department  
Coordinator  
jcarlson@nantucket-ma.gov

Tara Riley  
Town of Nantucket  
Natural Resources Department  
Shellfish Biologist  
triley@nantucket-ma.gov

Kaitlyn Shaw  
Town of Nantucket  
Natural Resources Department  
Water Resources Specialist  
kshaw@nantucket-ma.gov

Stephen Heck  
Ph.D. student at Stony Brook University  
heck.stephen@gmail.com

Anamarija Frankić, Ph.D.  
Research Professor, UNIZD & UMass Boston  
Director, Green Harbors Project® & Biomimicry LivingLabs®  
Anamarija.Frankic@umb.edu

Jon Kachmar  
The Nature Conservancy  
Massachusetts Coastal Program Director  
jkachmar@tnc.org

Matthew Pelikan  
The Nature Conservancy  
Massachusetts Restoration Ecologist  
mpelikan@tnc.org

Rick Karney  
Martha's Vineyard Shellfish Group  
Director/ Shellfish biologist  
mvsg@comcast.net

Dale Leavitt  
Roger Williams University  
Associate Professor of Biology

dleavitt@rwu.edu

Dr. Jonathon Grabowski  
Northeastern University  
Associate Professor  
J.Grabowski@neu.edu

Dr. Randall Hughes  
Northeastern University  
Assistant Professor  
Rhughes@neu.edu

Andrew McKenna-Foster  
Maria Mitchell Association  
Director of Natural Sciences  
amckennafoster@mariamitchell.org

## References

- "Atlantic Oyster Drill." *Chesapeake Bay Program*. 1 Sept. 2012. Web. 6 Jan. 2016.
- Baggett, L.P., S.P., Powers, R. Brumbaugh, L.D. Coen, B. DeAngelis, J. Greene, B. Hancock, S. Morlock. 2014. Oyster habitat restoration monitoring and assessment handbook. The Nature Conservancy, Arlington, VA, USA., 96pp.
- Beck, M.W., R.D. Brumbaugh, L. Airoidi, A. Carranza, L.D. Coen, C. Crawford, O. Defeo, G. Edgar, B. Hancock, M. Kay, H. Lenihan, M. Luckenbach, C. Toropova, and G. Zhang. 2011. Oyster reefs at risk and recommendations for conservation, restoration and management. *Bioscience* 61: 107-116.
- Beck, M.W., R.D., Brumbaugh, L., Airoidi, A., Carranza, L.D., Coen, C., Crawford, D., Defeo, G.J., Edgar, B., Hancock, M.C., Kay, H.S., Lenihan, M.W., Luckenbach, C.L., Toropova, G., Zhang. 2009. Shellfish reefs at risk: a global analysis of problems and solutions. The Nature Conservancy, Arlington, VA.
- Brumbaugh, R.D., M.W. Beck, L.D. Coen, L.Craig and P. Hicks. 2006. A Practitioners' Guide to the Design and Monitoring of Shellfish Restoration Projects: An ecosystem Services Approach. The Nature Conservancy, Arlington, VA
- Brumbaugh, R., L. Coen. 2009. Contemporary approaches for small-scale oyster reef restoration to address substrate versus recruitment limitation: a review and comments relevant for the Olympia oyster, *Ostrea lurida* carpenter 1864. *Journal of Shellfish Research*. 28:147-161
- Churchill, Neil. "Division of Marine Fisheries Dive Survey Protocol for Aquaculture Areas." Telephone interview. 14 July 2015
- Cohen, A., C. Zabin. 2009. Oyster shells as vectors for exotic organisms. *Journal of Shellfish Research*. 28:163-167
- daSilva Quintal, S. 2015. Buzzards Bay oyster spat monitoring study - 2014. Buzzards Bay Coalition, New Bedford, MA
- Eastern Oyster Biological Review Team. 2007. Status review of the eastern oyster (*Crassostrea virginica*). Report to the National Marine Fisheries Service, Northeast Regional Office. February 16, 2007. NOAA Tech. Memo. NMFS F/SPO-88, 105 p.
- Flimlin, G., B. Beal. 1993. Major predators of cultured shellfish. Northeastern Regional Aquaculture Center Bulletin No. 180
- Fourqurean, J.W., A. Willsie, C.D. Rose, and L.M. Rutten. 2001. Spatial and temporal patterns in sea grass community composition and productivity in south Florida. *Marine Biology* 138:341-354

- Gedan, K., M. Kirwan, E. Wolanski, E. Barbier, B. Silliman. 2010. The present and future role of coastal wetland vegetation in protecting shorelines: answering recent challenges to the paradigm. *Climate Change*
- George, L.M., K. DeSantiago, T. Palmer, J. Pollack. 2014. Oyster reef restoration: effect of alternative substrates on oyster recruitment and nekton habitat use. *J Coast Conservation*
- Gosselin LA, Qian PY. 1997. Juvenile mortality in benthic marine invertebrates. *Marine Ecology Program Series* 146: 265-282
- Grabowski, J., C. Baillie. 2013. Tisbury Great Pond oyster habitat restoration project. The Nature Conservancy
- Grabowski, J., R. Brumbaugh, R. Conrad, A. Keeler, J. Opaluch, C. Peterson, M. Piehler, S. Powers, A. Smyth. 2012. Economic valuation of ecosystem services provided by oyster reefs. *BioScience* 62: 900-909
- Green, M.A., G.G. Waldbusser, S.L Reilly, K. Emerson, S. O'Donnell. 2009. Death by dissolution: Sediment saturation state as a mortality factor for juvenile bivalves. *Limnol. Oceanogr.* 54: 1037
- Hewitt, J.E., S.F. Thrush, J. Halliday, C. Duffy. 2005. The importance of small-scale habitat structure for maintaining Beta diversity. *Ecology* 86(8): 1619-1626
- Hickey, J.M., T. Shields, J. Kennedy, K. Ford. 2015. Shellfish Planting Guidelines. Massachusetts Division of Marine Fisheries.
- Jordan, S., C. Stenger, M. Olson, R. Batiuk, and K. Mountford. 1992. Chesapeake Bay dissolved oxygen goal for restoration of living resources. United States Environmental Protection Agency, Chesapeake Bay Program, Annapolis, Maryland.
- Kellogg, L., J. Cornwell, M. Owens., K. Paytner. 2013. Denitrification and nutrient assimilation on a restored oyster reef. *Marine Ecology Program Series* 480: 1-19
- Kelly, R., Foley, M., Fisher, W., Feely, R., Halpern, B., Waldbusser, G., Caldwell, M. 2011. Mitigating local causes of ocean acidification with existing laws. *Science* 332: 1036-1037
- Kennedy, V.S. 1996. Biology of larvae and spat. In V.S. Kennedy, R.I.E. Newell and A.F. Eble, editors. *The Eastern Oyster Crassostrea virginica*. Maryland Sea Grant College, University of Maryland, College Park, Maryland. pp. 371-421.
- Kingsley-Smith, P.R. 2015. Eastern Oyster. *Species of Conservation Concern*
- Kingsley-Smith, P.R., Joyce, R.E., Arnott, S.A., Roumillat, W.A., McDonough, C.J. & Reichert, M.J.M. 2013. Habitat use of intertidal Eastern oyster (*Crassostrea virginica*) reefs by nekton in South Carolina estuaries. *J. Shellfish Res.* 31(4):1009-1021

- Kraeuter, J.N., M.J. Kennish, J. Dobarro, S.R. Fegley, G.E. Flimlin. 2003. Rehabilitation of the Northern quahog (Hard Clam) (*Mercenaria mercenaria*) habitats by shelling- 11 years in Barnegat Bay, New Jersey. *Journal of Shellfish Research* 22(1):61-67
- Kragt, M. 2012. Bioeconomic modelling: Integrating economic and environmental systems? International Environmental Modelling and Software Society
- Lenihan, H.S. 1999. Physical- biological coupling on oyster reefs: how habitat structure influences individual performance. *Ecol. Monographs* 69: 251-275
- Lenihan, H.S., Peterson, C.H., Byers, J.E., Grabowski, J.H., Thayer, G.W. & Colby, D.R. 2001. Cascading of habitat degradation: oyster reefs invaded by refugee fishes escaping stress. *Ecol. Appl.* 11:764-782
- MaKenzie, C.L. 1996. History of oystering in the United States and Canada, featuring North America's greatest oyster estuaries. *Marine Fisheries Review*. 58(4): 1-78
- Mann, R., Harding, J.M. 1998. Continue trophic studies on constructed "restored" oyster reefs. Annual research report to the U.S. Environmental Protection Agency, Chesapeake Bay Program, Living Resources Committee, Virginia Institute of Marine Science, Gloucester Point, VA. 71 pp.
- Mann, R., Powell, E.N. 2007. Why oyster restoration goals in the Chesapeake Bay are not and probably cannot be achieved. *Journal of Shellfish Research* 26:905-917.
- Massachusetts Municipal Association. 2014. 3 Cape Cod Towns use oysters to improve water quality. Boston, MA. Accessed Feb. 22, 2016. <http://www.mma.org/more-community-corner/14120-3-cape-cod-towns-use-oysters-to-improve-water-quality>
- Meritt, D., D. Webster. Remote Setting Systems. University of Maryland Extension Oyster Aquaculture Technology Series
- Meyer D.L., Townsend E.C., Thayer G.W. 1997. Stabilization and Erosion Control Value of Oyster Cultch for Intertidal Marsh. *Restoration Ecology* 5:93-99
- Natural Heritage Endangered Species Program. 2016. Massachusetts List of Endangered, Threatened and Special Concern Species. Westborough, MA. Accessed Feb. 22, 2016. <http://www.mass.gov/eea/agencies/dfg/dfw/natural-heritage/species-information-and-conservation/mesa-list/list-of-rare-species-in-massachusetts.html>
- Newell, R.I.E., C.J. Langdon. 1996. Mechanisms and physiology of larval and adult feeding. *In*: V.S. Kennedy, R.I.E. Newell and A.F. Eble, (eds). *The Eastern Oyster Crassostrea virginica*. Maryland Sea Grant College, University of Maryland, College Park, Maryland. pp. 185-229

- Newell, R.I.E., G.S. Alspach, Jr., V.S. Kennedy, D. Jacobs. 2000. Mortality of newly metamorphosed eastern oysters (*Crassostrea virginica*) in mesohaline Chesapeake Bay. *Marine Biology* 136: 665-67
- Newell, R.I.E., E.W. Koch. 2004. Modeling sea grass density and distribution in response to changes in turbidity stemming from bivalve filtration of substrate type and tidal height. *J. Shellfish Res.* 19: 387-395
- Newell R, Fisher T.R., Holyoke R, Cornwell J. 2005. Influence of eastern oysters on nitrogen and phosphorus regeneration in Chesapeake Bay, USA. In: Dame R, Olenin S (eds) *The comparative roles of suspension-feeders in eco-systems*. Kluwer, Dordrecht, p 93–120
- Norton, J. 2010. Oyster farming. *Chesapeake Quarterly*, December 2015 issue. Retrieved from <http://www.chesapeakequarterly.net/V14N4/side1/>
- Peabody, B., Griffin, K. 2008. Restoring the Olympia Oyster, *Ostrea conchaphila*. *Habitat Connections* 6 (2):1-6
- Pelikan, M., J. Kachmar, K. Lombard, R. Konisky. 2015. Nasketucket Bay (Fairhaven) oyster restoration. The Nature Conservancy.
- Piazza B.P., Banks P.D., Peyre, M.K. 2005. The potential for created oyster shell reefs as a sustainable shoreline protection strategy in Louisiana. *Restor. Ecol.* 13:499–506
- Posey, M.H., Alphin, T.D., Powell, C.M., Townsend, E. 1999. Oyster reefs as habitat for fish and decapods. In: M. W. Luckenbach, R. Mann & J. A. Wesson, (eds), *Oyster reef habitat restoration: a synopsis and synthesis of approaches*. Virginia Institute of Marine Science Press, Gloucester Point, VA, pp. 229-237
- Powell, E.N., Kraeuter, J.N., Ashton-Alcox, K.A. 2006. How long does oyster shell last on an oyster reef? *Estuarine Coastal and Shelf Science* 69:531-542
- Powers, S.P., C.H. Peterson, J.H. Grabowski, H.S. Lenihan. 2009. Evaluating the success of constructed oyster reefs in no-harvest sanctuaries: implications for restoration. *Marine Ecology Progress Series* 389: 159-170
- Rose, J., S. Bricker., M. Tedesco., G. Wikfors. 2014. A role for shellfish aquaculture in coastal nitrogen management. *Environmental Science and Technology* 48: 2519- 2525
- Schulte DM, Burke RP, Lipcius RN. 2009. Unprecedented restoration of a native oyster metapopulation. *Science* 325:1124–1128
- Sellars, M.A., and J.G. Stanley. 1984. Species profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic) - American oyster. U.S. Fish Wildl. Serv. U.S. Army Corps of Engineers, TR EL-82-4. 15pp.

- Shellfish Management Plan. 2010. Nantucket, MA. Accessed Feb. 1, 2016.  
<http://www.nantucket-ma.gov/DocumentCenter/Home/View/88>
- Shumway, S.E. 1996. Natural environmental factors. In: V.V. Kennedy, R.I.E. Newell and A.F. Eble, editors. The Eastern Oyster *Crassostrea virginica*. Maryland Sea Grant College, University of Maryland. Pp.467-513
- Schulte D.M., Burke R.P., Lipcius R.N. 2009. Unprecedented restoration of a native oyster metapopulation. *Science* 325:1124–1128.
- Swann, L. 2008. The use of living shorelines to mitigate the effects of storm events on Dauphin Island, Alabama, USA. *Am Fish Soc Symp* 64:47–57
- Thayer, Gordon W., Teresa A. McTigue, Ronald J. Salz, David H. Merkey, Felicity M. Burrows, and Perry F. Gayaldo, (eds.). 2005. Science-Based Restoration Monitoring of Coastal Habitats, Volume Two: Tools for Monitoring Coastal Habitats. NOAA Coastal Ocean Program Decision Analysis Series No. 23. NOAA National Centers for Coastal Ocean Science, Silver Spring, MD. 628 pp. plus appendices
- Town of Nantucket. 2015. Shellfishing Policy and Regulations. Nantucket, MA. Accessed Feb.1, 2016. <http://www.nantucket-ma.gov/DocumentCenter/Home/View/8778>
- Waldbusser, G., Voigt, E., Bergschneider, H., Green, M., Newell, R. 2011. Biocalcification in the Eastern Oyster in Relation to Long-term Trends in Chesapeake Bay pH. *Estuaries Coasts*. 34: 221
- Wilberg, M.J., M.E. Livings, J.S. Barkman, B.T. Morris, and J.M. Robinson. 2011. Overfishing, habitat loss, and potential extirpation of oysters in upper Chesapeake Bay. *Marine Ecology Progress Series* 436:131-144
- Zu Ermgassen, P.S.E., M.D. Spalding, B. Blake, L.D. Coen, B. Dumbauld, S. Geiger, J.H. Grabowski, R. Grizzle, M. Luckenbach, K. McGraw, W. Rodney, J.L. Ruesink, S.P. Powers, and R.D. Brumbaugh. 2012. Historical ecology with real numbers: past and present extent and biomass of an imperiled estuarine habitat. *Proceedings of the Royal Society B: Biological Sciences* 279:3393-3400

## Appendix I

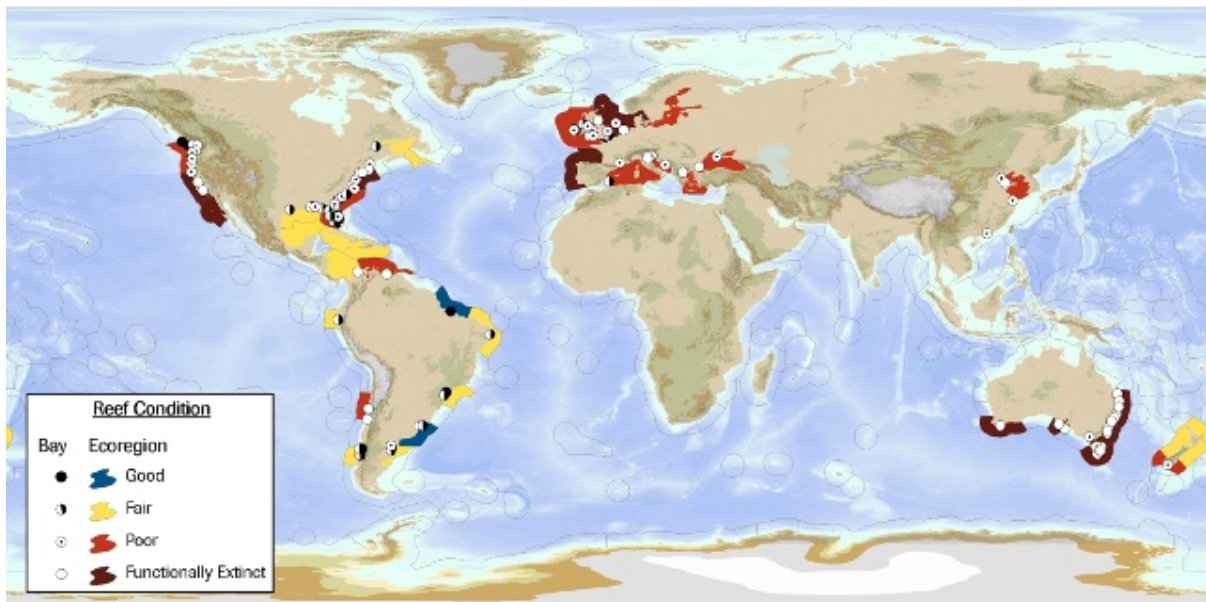


Figure 1. Global conditions comparing historic to current oyster reefs worldwide ranging from good (<50% loss) to functionally extinct (>99% lost) (Beck et al. 2009).

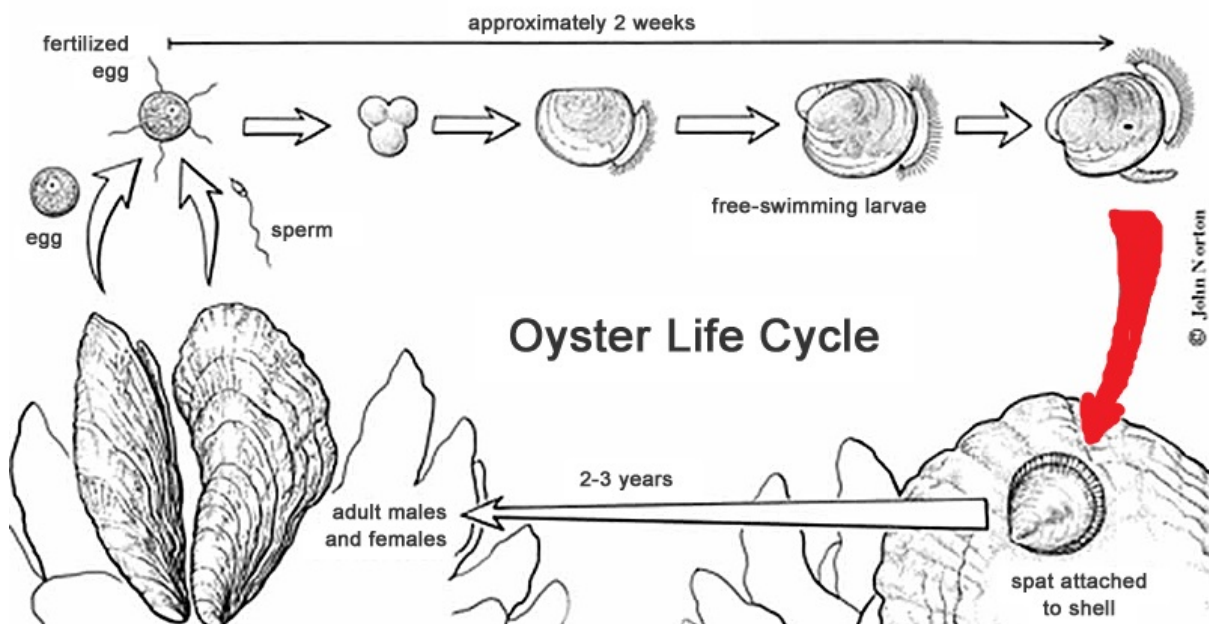


Figure 2. Oyster life cycle (Norton et al. 2010).

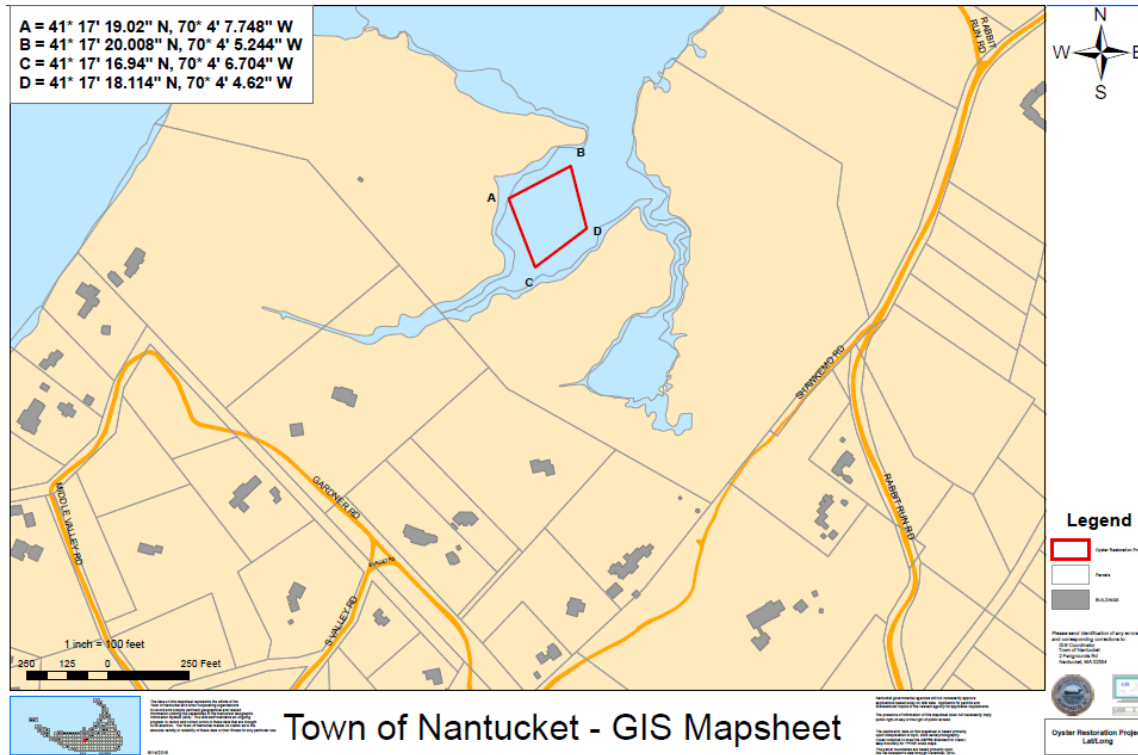


Figure 3. One acre area in Shimmo for reef establishment.



Figure 6. Oyster domes constructed out of concrete. The left depicts a dome covered with oysters and the right is a dome after construction (<http://reefinnovations.com/>).

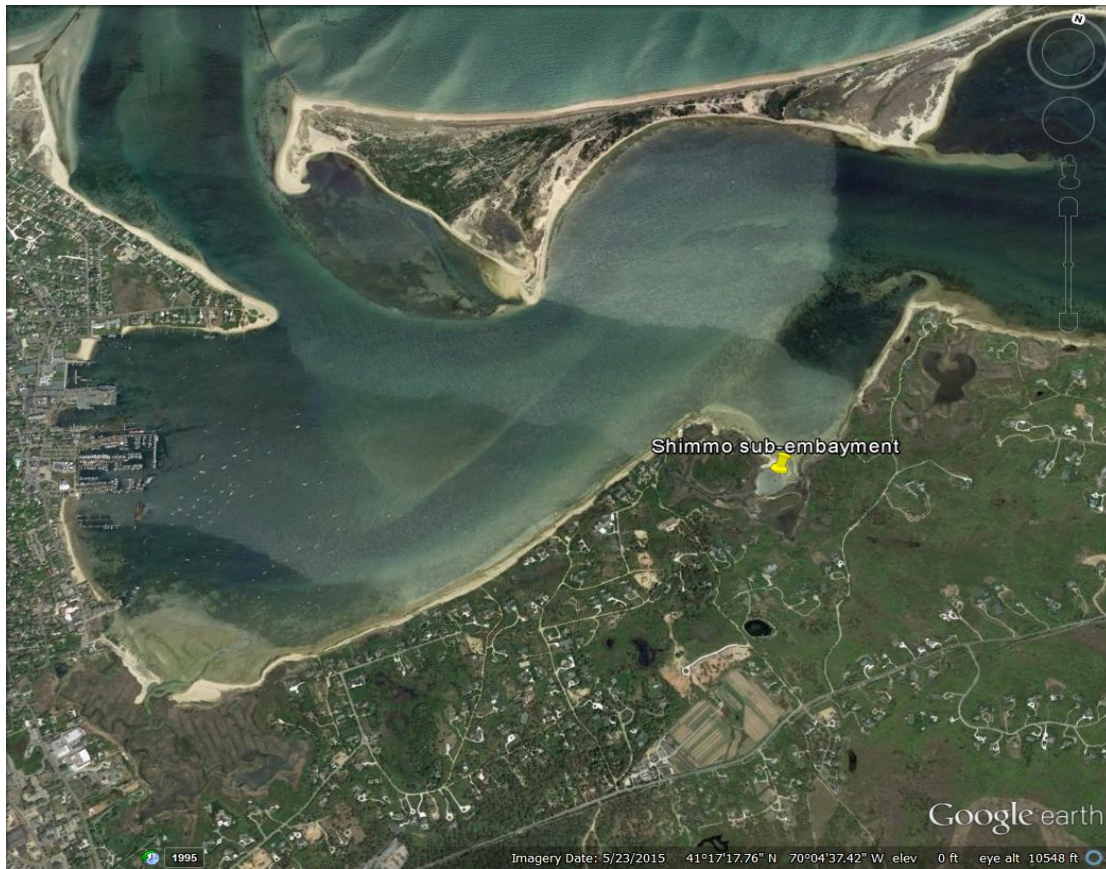


Figure 8. Shimmo Creek (yellow pin) is a sub-embayment of Nantucket Harbor.



Figure 9. A closer look at Shimmo sub-embayment where the reef will be located.

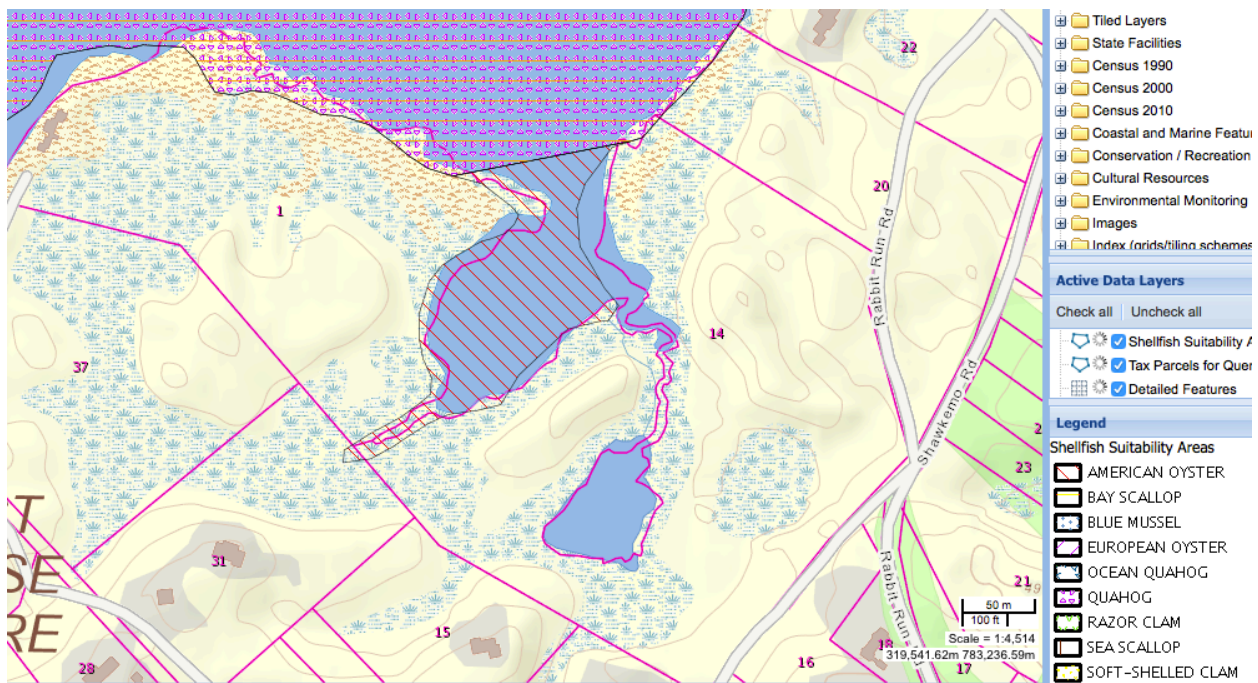


Figure 10. MassGIS Oliver mapping shellfish suitability areas in Nantucket, MA. Shimmo is suitable for growing American Oysters.

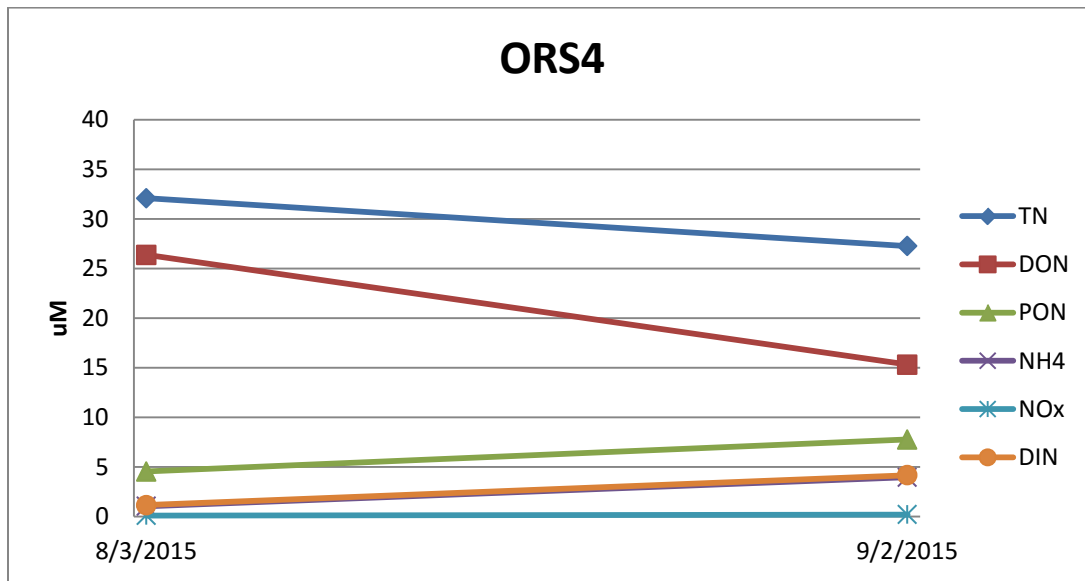


Figure 11. Water quality data for: total nitrogen, dissolved organic nitrogen, particulate organic nitrogen, ammonium, nitrate + nitrite, and dissolved inorganic nitrogen taken for two sampling events in Shimmo Creek. See table 3 for exact values and more water quality parameters.

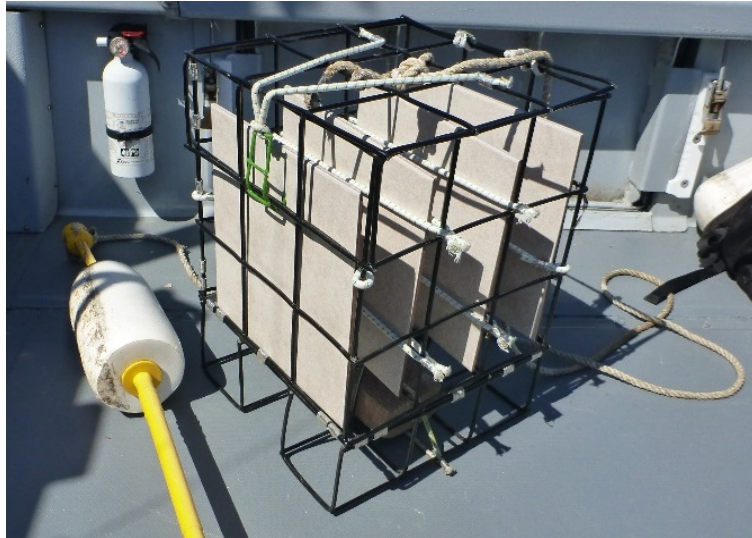


Figure 12. Spat collector that holds four unglazed tiles used for recruitment studies (daSilva Quintal et al. 2015).



Figure 13. Two unglazed tiles covered in oysters, barnacles, common jingle shells (daSilva Quintal et al. 2015).

Table 1. Objectives fulfilled by oyster restoration in the Shellfish Management Plan.

Section	Goal	Objective	Recommendation	Description	Priority	Addressed by Oyster Reef
Habitat Management	1	1	5	Conduct and/or support studies to investigate the role that environmental changes may have in altering shellfish populations on Nantucket, including sea level rise, ocean acidification, and climate change. As part of this, continue, and where appropriate, enhance efforts to record water temperature, changes in pH, and details about when the Harbors freeze over.	Medium	Water quality devices (HOBO and SONDE) will be deployed pre and post reef construction to give real time water quality data
Habitat Management	1	2	3	Develop and implement a cost effective strategy to protect/restore eelgrass in locations of significance to shellfish resource—both within <sup>?</sup> and outside Nantucket and Madaket Harbors. This strategy should take into consideration options such as propagating eelgrass, reseeding areas, and removing stressors (e.g., moorings, excess nutrients) to existing and potential eelgrass habitats.	Medium	Oyster's filtration abilities reduce suspended sediments and phytoplankton concentrations increasing light penetration through the water column aiding in eelgrass establishment and growth (Newell et al. 2004).
Habitat Management	1	3	2	Work with the Nantucket Department of Public Works to institute a shell recycling program where most, if not all, shells are returned to the Harbors for pH buffering and settlement substrate purposes (potentially with assistance from fishermen). Ensure that the deposition of shells does not harm existing habitat features (such as eelgrass beds) or create new habitat dominated by predators. Adhere to DMF's Shellfish Planting Guidelines for placing shells in the water: "Oyster, quahog and softshell clam shell used as cultch shall be aged on land for a minimum of one year. Shell from other species of bivalves such as surf clam, ocean quahog, scallops and mussels may be used without limitations. All issues regarding approved shell cultch must be addressed by Marine Fisheries prior to placement into coastal waters." (Hickey et al., 2012). Conduct research to identify the most appropriate locations for returning the shells and monitor the deposition sites to better understand the impacts of such activities.	High	Shells reclaimed from this program will be used to construct the oyster reef. Research has been conducted to locate an appropriate site for the reef and the reef will be thoroughly monitored.
Habitat Management	1	3	3	Continue to monitor dissolved oxygen in benthic areas of the Harbors, and expand monitoring to include monitoring of sediment acidity.	Medium	Water quality devices (HOBO and SONDE) will be deployed pre and post reef construction to give real time dissolved oxygen data.
Habitat Management	1	3	4	Continue monitoring spat settlement throughout the waters of Nantucket by way of spat collection and enumeration.	Medium	Oyster spat collectors will be deployed in Shimmo Creek to monitor natural sets.
Habitat Management	1	3	5	Conduct collaborative annual surveys of juvenile shellfish stocks to assess the areas of spatfall to aid in management decision making.	High	Annual surveys will be conducted on the reef to monitor shellfish stocks.

Shellfish Resources	1	1	1	Develop and implement a strategy to track the effectiveness of propagation activities in terms of supplementing the commercial and recreational harvests. As part of this, identify locations best suited for larval release (e.g., areas with larval retention), examine the timing of larval release in terms of survival, and conduct post set release and associated monitoring for survivability.	High	The reef will be supplemented with hatchery grown oysters until it becomes self-sustaining. Annual surveys will monitor post-set release survivability.
Shellfish Resources	1	1	2	Continue current propagation efforts such as the larval release program and, based on the results of the study of propagation effectiveness, consider pursuing opportunities to expand propagation activities, including expansion to different species (i.e., oysters).	High	In 2014, propagation has expanded to oysters. Oysters were spawned, larvae reared, and remotely set on recycled oyster shell provided by the Shell Recycling Program.
Shellfish Resources	1	3	1	Continue to develop spawning sanctuaries, through the use of spawning cages, to increase larval supply, and monitor impacts of sanctuaries. Particular focus should be on utilizing areas with high larval retention and evaluating the manipulation of water flow for larval retention.	High	The reef will be a spawning sanctuary which means no recreational or commercial oyster harvesting. Oyster larvae from the reef will aid in stocking other areas in the Harbor.
Shellfish Resources	1	3	2	Institute new steps—and continue existing efforts—to identify spawning events and monitor spat levels in the Harbors such as by the strategic placement of spat bags strategically around the Harbors.	Medium	Oyster spat collectors will be deployed in Shimmo Creek to monitor spawning events and natural sets.
Shellfish Resources	1	3	3	Continue larval release at various locations throughout Nantucket waters and evaluate its effectiveness in terms of localized recruitment of spat. Investigate whether or not the timing of the releases affects their effectiveness at enhancing local populations.	High	The reef will be supplemented with hatchery grown larvae/spat until it becomes self-sustaining. Annual surveys will determine its effectiveness on local populations.
Shellfish Resources	2	1	1	Measure and monitor predator abundance in Nantucket waters (in part through a survey of by catch) and measure impacts on shellfish resources during the various life stages for each species. Understand the impacts of native versus non native predators and implement a predator management protocol as appropriate, perhaps based on the identification of an “over abundance” (which would need to be defined) of predators in the ecosystem. As part of the protocol, conduct research to understand the impacts of predator removal—both on the harvested resources and on the biological communities in the Harbors. Specifically look at the impacts of the mud blister worm (Polydora).	Low	Predator pilot project was deployed in Fall of 2015 on a “mini reef” and will continue to be monitored for 1 year. Predators will be monitored through dive surveys, time-lapse cameras, and seine nets.
Shellfish Resources	3	1	2	Better understand and define the biological traits of and stressors to bay scallops, quahogs, conch, oysters, softshelled clams, and other harvested shellfish. Use that knowledge to make informed management decisions. Specific topics of interest include (1) the relationship between spat recruitment and post set spat survival as it relates to the overall abundance of shellfish, and (2) the genetic variability among harvested shellfish.	Medium	Physical and biological stressors will be monitored on the oyster reef as well as spat recruitment and post-set spat survival.
Support Commercial Fishery	1	1	3	Develop marketing strategies to enhance the value of Nantucket shellfish by products (e.g., shells as a buffering source for restoration projects, viscera as a protein source, guts as bait or food, gonads as food).	Low	Addressed by “Shuck It for Nantucket”: oyster and quahog Shell Recycling Program

Table 2. Water quality parameters from two sampling dates at Shimmo Creek.

<b>Water Quality Parameters</b>	<b>8/3/2015</b>	<b>9/2/2015</b>	<b>Average</b>
Salinity (ppt)	31.60	31.50	31.55
Conductivity (mS)	48.80	48.40	48.60
Dissolved Oxygen (mg/L)	3.76	3.96	3.86
Temperature (°C)	23.60	22.70	23.15
Phosphate (mg/L)	0.04	0.08	0.06
Ammonium (uM)	1.05	3.97	2.51
Nitrate + Nitrite (uM)	0.11	0.21	0.16
Dissolved Inorganic Nitrogen (uM)	1.16	4.18	2.67
Particulate Organic Nitrogen (uM)	4.55	7.77	6.16
Dissolved Organic Nitrogen (uM)	26.37	15.31	20.84
Total Nitrogen (uM)	32.08	27.26	29.67
Total Pigments (ug/L)	2.10	5.19	3.65

## Appendix II

### 2015 Oyster Predator Pilot Project

#### Overview

Over the past 100 years, there has been an estimated 85% decline in oyster habitat and populations world-wide (Beck et al. 2011, Figure 1.). In the United States, there has been an estimated 88% decline in oyster biomass with populations along the Atlantic coast exhibiting the greatest loss (zu Ermgassen et al. 2012). This is due to a number of reasons including: over-harvesting, not returning suitable substrate (oyster shell) back to the water, habitat loss, sedimentation, disease and poor water quality (Wilberg et al. 2011). Wild oyster populations in Nantucket waters used to be plentiful but currently are hard to find (anecdotal evidence). Reduced populations can be found in Easy Street Basin and Sesachacha Pond. In order to restore oysters in Nantucket, the Natural Resources Department (NRD) plans to establish an oyster reef in 2017. In the last two years, NRD has expanded their shellfish production at the Brant Point Hatchery to include oyster spat on shell during the shoulder season.

In June of 2015, 30,000 2 millimeter (mm) diploid oysters were shipped to Nantucket from Mook Sea Farms Inc. for growth studies. They are currently in 4 bottom cages at different locations in Nantucket harbor (Figure 2). Oysters were measured once a month from June to October and will be overwintered. The study will provide information about winter survival and growth rates at the four locations. Although the bags will protect oysters from larger predators they will be exposed to small predators that can fit through the bag's 4 mm holes.

In August of 2015, oyster broodstock were conditioned for 3 days, fed algae and spawned producing 22.82 million eggs. After rearing larvae for 23 days, 3.21 million larvae were split between two tanks for the remote set process. During this processes, larvae attach to cured, recycled oyster shell by their byssal threads and remain there for the rest of their life. The oysters grew in the outside tank for about 3 weeks averaging 4.67mm in size before they were deployed for the predator pilot project.

#### Objectives

1. Quantify survival of spat on shell that is less than 10 mm in length when exposed to various predators at the prospective reef site.
2. Test if two different vertical reliefs 0.10m (4") and 0.15m (6") contribute to spat survival.

#### Predators

"Little is known about the role of predation in reducing the numbers of juvenile bivalves (spat) in the first few weeks following settlement" (Gosselin and Qian et al. 1997). This pilot project focuses on spat survival (less than 10 mm in length) three to four weeks post settlement in Shimmo Bend which is located within Nantucket Harbor.

Oyster predators vary from gastropods to vertebrates. There are a number of predators that will be monitored during this study. According to Flimlin et al. 1993, oyster predators include: 'blue crabs (*Callinectes sapidus*), green crabs (*Carcinus maenas*), mud crabs (*Dsypanopeus sayi* and *Panopeus herbstii*), whelks (*Busycon carica* and *Busycotypus canaliculatus*), oyster drills (*Eupleura caudate* and *Urosalpinx cinerea*), oyster flatworms (*Stylochus ellopticus*), mud blister worms (*Polydora websteri*), boring sponge (*Cliona celata*), comb jellies (*Bolinopsis infundibulum*), and diving ducks (*Eider ducks*, gulls, oyster catchers).

Blue and green crabs can prey on oysters that are between 6 and 51mm in length. Mud crabs eat smaller spat that are between 12 and 19 mm in length. Oyster drills attach anywhere on the oyster shell and use sulfuric acid to drill a hole and dissolve tissue in both juvenile and adult oysters. Comb jellies and other filter feeders prey on oyster larvae. The oyster flatworm grows to about 1 inch and can slide between the valves of any shell size and feed on the tissue.'

Newell et al 2000 found during an experiment in the Chesapeake Bay during the summer (ambient water temperature 27°C) that unprotected spat (no predator exclusion) less than 2 mm had a mortality rate of 21.9% after 3 days in the estuary compared to those in 400 um and 800 um bags (9.4% and 10.1%). In all samples, a high abundance of *Stylochus ellopticus* was present and in the laboratory experiment this was the only small spat predator noted (Newell et al. 2000). "The effects of micro-predators on recently settled young organisms may potentially be more significant than the effects of macro-predators on older and larger life stages" (Newell et al. 2000).

Flimlin et al. (1993) refers to boring sponge, boring clams, and mud worms as pests rather than predators. "Many of these infestations are natural associations and in general, most oysters survive. Thus, these associations do not seem to be having an effect at the population level". Boring sponge bores into the shell causing the hinge and shell to be compromised. The blister worm produces blisters on the abductor muscle causing it to weaken which results in the oyster unable to close its shell.

## Methods

Dive surveys in Shimmo were conducted in August using the Division of Marine Fisheries Aquaculture Dive Survey Protocol. The protocol required three to five transects needed to be conducted for the designated area (Figure 3). Ten 0.30m<sup>2</sup> transects were randomly chosen along each transect line and a garden cultivator was used to assess shellfish abundance (Churchill, personal communication). Information gathered from the August dive surveys concluded that a majority of the bottom type was anaerobic soft sediment with a penetration depth up to 0.30m. The sediment was covered with a layer of detritus, 3 quahogs were found but no eelgrass (*Zostera marina*) was present. According to the Division of Marine Fisheries guidelines, Shimmo would qualify as an acceptable site for aquaculture or shellfish restoration. In addition, according to OLIVER from MassGIS (Figure 4) this area is suitable for growing American Oysters (*Crassostrea virginica*). Shimmo is easily accessible by both boat and foot and out of the way from harbor users.

Don Meritt from the University of Maryland suggested that a minimum of 30 shells from each tank should be examined and the more shells examined the better for total spat estimates. Prior to the study, the number of spat on shell was evaluated by randomly picking 40 shells from each shell bag.

On October 7, 2015 the predator pilot project was deployed in Shimmo (Figure 5). The area chosen was sub-tidal with a depth of 0.55m at low tide and 1.5 m depth at high tide. Eight plastic clam trays (1.13m x 0.82m) were used to contain spat on shell. This method was used in an experiment by George et al. (2014) when testing spat set rate on different substrate types. The trays allow the material to be easily removed from the water when the pilot project is done. For this project, trays were laid in two rows (4 trays in each row) side by side for a total dimension of 4.51m x 1.64m. A total of 40 bags containing 219,537 spat on shell were deployed to serve as a "mini reef". The area was marked with metal stakes and programmed in the GPS so it can be easily located in the spring.

Schulte et al. (2009) found that reef height was a major influence for oyster reef success because it drove oyster abundance and density. High relief reefs maximize oyster growth and survival and minimize disease and sedimentation due to optimal flow rates. The row closest to the beach was designated to have a 0.10m reef relief height (low relief) and each tray contained 4 bags of spat on shell (T1H, T1B, T2H, T2B). The second row was designated as the 0.15m relief height (high relief) and each tray contained 6 bags (see Table 1). These two reliefs were chosen because The Nature Conservancy (TNC) found that using a layer of shell at least 10 cm (4”) in Tisbury Pond (Martha’s Vineyard, MA) and Nasketucket Bay (Fairhaven, MA) was most effective (Grabowski et al. 2013, Pelikan et al. 2015). The TNC found that reef height in Tisbury Pond decreased 10 cm in 12 months or 56.2% due to shell material sinking into the soft benthic sediment. Powers et al. (2009) suggested a minimum height for restored reefs to be 20 cm (~8”), which allows shell to sink but still provides sufficient reef height for spat recruitment and survival.

### **Monitoring**

In order to evaluate different factors in reef success, the mini reef will stay in the water through next fall 2016. In New England, ice can be a factor driving spat and adult oyster survival. Shimmo is susceptible to freezing, therefore by keeping the reef in through the winter we can glean if a water depth of 0.5m at low tide is sufficient for oyster survival.

In early summer of 2016, NRD employees will dive the mini reef once a month in order to observe predators and other species found in the area. At this time, if available, 20 random spat from each tray will be measured (George et al. 2014). In addition, two time lapse cameras with red LED lights will be placed in the middle of the reef to record predators. This will serve as another way to evaluate species abundance. A seine net will be used monthly throughout the summer to evaluate fish abundance. Water quality parameters will be conducted bi-monthly and when additional surveys are performed.

In the fall, natural spat recruitment will be evaluated by Scuba diving and randomly collecting 20 shells from each tray (George et al. 2014). It is better to do this in the fall because the 2<sup>nd</sup> age class of spat will be large enough to see with the naked eye. In September, a decision will be made to either keep the mini reef in until the reef is built or take it out in the fall. If it remains intact 0.25 m<sup>2</sup> quadrat samples will be taken from each tray to quantify oyster densities (Powers et al. 2009). This will be done diving with a mesh bag and all shell within the quadrat will be excavated and placed in the bag for later analysis. The length and number of oysters in each quadrat will be recorded. If the project needs to be removed before the reef is built then NRD employees will do so.

### **Timeline**

October 2015: Predator pilot project deployed  
June 2016: Time lapse cameras and red LED lights deployed  
June, July, August, September 2016: Dive and seine net surveys  
October 2016: Natural spat recruitment dive surveys

### **Conclusion**

The mini reef success will help determine multiple factors when planning the first oyster restoration project in Nantucket. For example, if one relief height is optimal over the other for

oyster survival and sedimentation rates, then that data will be used in determining how much shell is needed to establish the reef. Predator rates and spat survival can help determine if the reef needs to be seeded with more than the recommended amount of 250,000 spat per acre (TNC et al. 2013). When the reef is established, data gathered during the pilot project will be used as a baseline for comparing species abundance (oysters, predators, fish, etc.), natural recruitment, and spat growth and survival.

## Literature Cited

- Beck, M.W., R.D. Brumbaugh, L. Airoidi, A. Carranza, L.D. Coen, C. Crawford, O. Defeo, G. Edgar, B. Hancock, M. Kay, H. Lenihan, M. Luckenbach, C. Toropova, and G. Zhang. 2011. Oyster reefs at risk and recommendations for conservation, restoration and management. *Bioscience* 61: 107-116.
- Churchill, Neil. "Division of Marine Fisheries Dive Survey Protocol for Aquaculture Areas." Telephone interview. 14 July 2015.
- Eastern Oyster Biological Review Team. 2007. Status review of the eastern oyster (*Crassostrea virginica*). Report to the National Marine Fisheries Service, Northeast Regional Office. February 16, 2007. NOAA Tech. Memo. NMFS F/SPO-88, 105 p.
- Flimlin, G., B. Beal. 1993. Major predators of cultured shellfish. Northeastern Regional Aquaculture Center Bulletin No. 180.
- George, L.M., K. DeSantiago, T. Palmer, J. Pollack. 2014. Oyster reef restoration: effect of alternative substrates on oyster recruitment and nekton habitat use. *J Coast Conservation*.
- Gosselin LA, Qian PY. 1997. Juvenile mortality in benthic marine invertebrates. *Marine Ecology Program Series* 146: 265-282.
- Grabowski, J., C. Baillie. 2013. Tisbury Great Pond oyster habitat restoration project. The Nature Conservancy.
- Meritt, D., D. Webster. Remote Setting Systems. University of Maryland Extension Oyster Aquaculture Technology Series.
- Newell, R.I.E., G.S. Alspach, Jr., V.S. Kennedy, D. Jacobs. 2000. Mortality of newly metamorphosed eastern oysters (*Crassostrea virginica*) in mesohaline Chesapeake Bay. *Marine Biology* 136: 665-676.
- Pelikan, M., J. Kachmar, K. Lombard, R. Konisky. 2015. Nasketucket Bay (Fairhaven) oyster restoration. The Nature Conservancy.
- Powers, S.P., C.H. Peterson, J.H. Grabowski, H.S. Lenihan. 2009. Evaluating the success of constructed oyster reefs in no-harvest sanctuaries: implications for restoration. *Marine Ecology Progress Series* 389: 159-170.
- Schulte DM, Burke RP, Lipcius RN (2009) Unprecedented restoration of a native oyster metapopulation. *Science* 325:1124–1128.
- Wilberg, M.J., M.E. Livings, J.S. Barkman, B.T. Morris, and J.M. Robinson. 2011. Overfishing, habitat loss, and potential extirpation of oysters in upper Chesapeake Bay. *Marine Ecology Progress Series* 436:131-144.

Zu Ermgassen, P.S.E., M.D. Spalding, B. Blake, L.D. Coen, B. Dumbauld, S. Geiger, J.H. Grabowski, R. Grizzle, M. Luckenbach, K. McGraw, W. Rodney, J.L. Ruesink, S.P. Powers, and R.D. Brumbaugh. 2012. Historical ecology with real numbers: past and present extent and biomass of an imperiled estuarine habitat. *Proceedings of the Royal Society B: Biological Sciences* 279:3393-3400.

## Predator Study Appendix

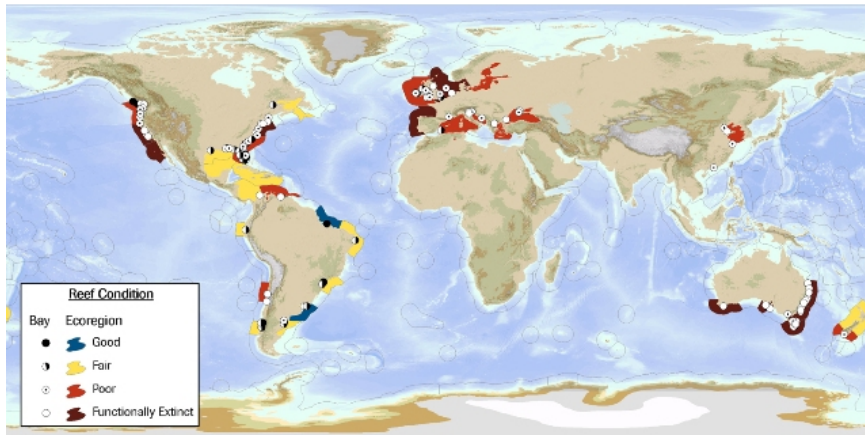


Figure 1. Oyster reef conditions worldwide.

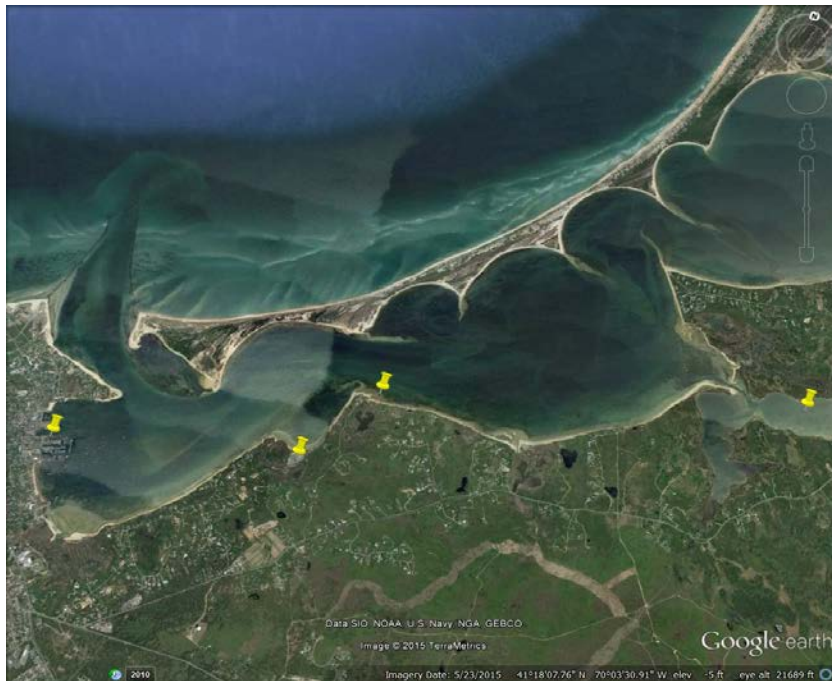


Figure 2. Four locations (Easy Street Basin, Shimmo, Duck's Holm, and Polpis) of oyster bottom cages in Nantucket Harbor.



Figure 3. Locations of dive transect lines in Shimmo.

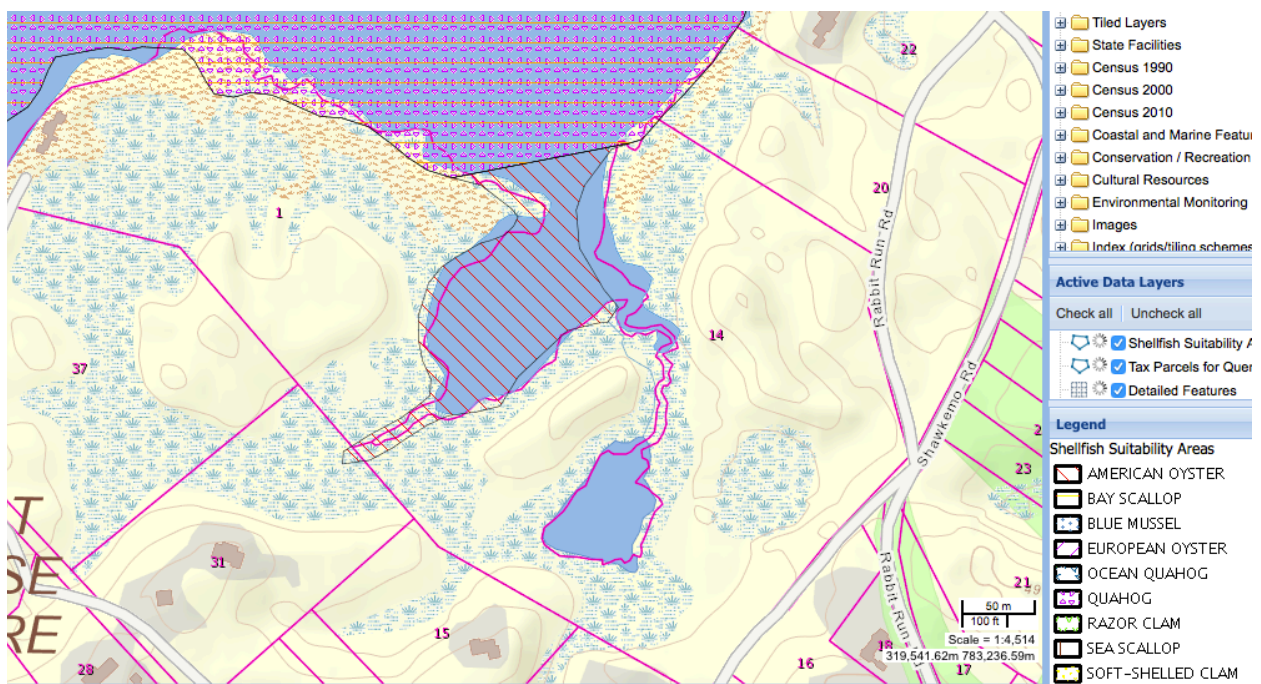


Figure 4. According to MassGIS OLIVER shellfish suitability map American oysters are suitable to grow in Shimmo.



Figure 5. Map of pilot project in Shimmo. The row labeled 4'' is for the 4'' reef relief height and the row labeled 6'' is for the 6'' reef relief height.

Table 1. Bags designated for trays 1- 4 for 6'' relief height (see Figure 5).

Tray 1	Tray 2	Tray 3	Tray 4
T1H	T1B	T2B	T1H
T1B	T1B sample	T2B	T1H
T1H	T1H sample	T1B	T1B
T2H	T2B	T1H	T1H
T2B	T2H	T1H	T1H
T1B	Not labeled	T1B	T1B
T2B sample (small bag)	T2H sample (small bag)	T1H sample (small bag)	

Table 2. Number of spat per bag deployed in Shimmo totaling 219,537 spat on shell.

Tank 1 Hanging Bags	Spat Per Bag	Tank 1 Bottom Bags	Spat Per Bag	Tank 2 Hanging Bags	Spat Per Bag	Tank 2 Bottom Bags	Spat Per Bag
bag 1H	4550	bag 1B	11252.5	bag 1H	1330	bag 1B	1260
bag 2H	5197	bag 2B	19407.5	bag 2H	910	bag 2B	2817.5
bag 3H	5705	bag 3B	8050	bag 3H	682.5	bag 3B	1330
bag 4H	6405	bag 4B	8137.5	bag 4H	560	bag 4B	2520
bag 5H	4760	bag 5B	3972.5	bag 5H	2642.5	bag 5B	1907.5
bag 6H	4935	bag 6B	10745	bag 6H	1015	bag 6B	1942.5
bag 7H	1802	bag 7B	6912.5	bag 7H	560	bag 7B	577.5
bag 8H	1942.5	bag 8B	10290	bag 8H	1735.5	bag 8B	2275
bag 9H	7560	bag 9B	11602.5	Total:	9435.5	Total:	14630
bag 10H	11165	bag 10B	24850				
bag 11H	8488	bag 11B	17745				
Total:	62509.5	Total:	132965				